Space Domain Awareness

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Abstract

While Space Domain Awareness (SDA), including all of space surveillance and characterization of all space objects and environments, is critical for national and economic security, SDA capabilities cannot be developed independent of cost. This presentation will describe a new approach to SDA being developed by the Defense Advanced Projects Agency (DARPA) and other agencies. This approach endeavors to integrate the data from a wide range of current and future SDA capabilities for a fraction of the current costs by utilizing a new methodology for obtaining data. This approach will not just provide more SDA data for a reduced cost, but has the potential to also increase the amount of knowledge gained from the data.

1. INTRODUCTION

For decades, the Space Surveillance Network has been tracking orbital objects and maintaining a catalog that allows space operators to safely operate satellites for a variety of uses. Even as new advanced sensors are deployed (such as the Space Fence), orbital populations continue to grow at an ever increasing rate. Most estimates of the requirements to safely operate in this congested, potentially contentious, environment examine the raw number of objects in orbit. Over the last couple decades, bytes have become the standard metric of progress, and massively distributed systems have demonstrated the ability to effectively collect and process information. Examples include the dominance of cluster based supercomputers, and the phenomenal success of Google. In this paper, the requirements to maintain complete Space Domain Awareness (SDA) are examined from a perspective of the data volume required. This work attempts to frame the SDA challenge in this new paradigm, and examine distributed options to gather the needed information. While data volumes are naturally dominated to first order by the number of objects, this estimate also attempts to account for the additional demands of characterizing unknown objects and maintaining accurate tracking of active space objects. Data types for different orbital regimes and levels of knowledge are estimated and compared to the capabilities of existing observatory assets in the academic and private sectors. The comparison shows that there are significant data needs that can be fulfilled by creatively leveraging these assets.

2. SDA DATA NEEDS ESTIMATE

Space Domain Awareness is the ability to detect, track, and characterize passive and active space objects. Most systematic efforts to achieve this goal have focused on the detection and tracking aspects, addressing characterization in an ad-hoc fashion. The current space catalog contains over 16,000 known objects, but it is widely recognized that the catalog is incomplete and many additional resident space objects exist, particularly if smaller size objects are included [1]. In addition, it is also generally accepted that the number of objects, both passive and active, is steadily increasing. Complete and true space domain awareness, then, must account for both an expansion in the size of the general catalog, as well as the capacity to routinely characterize objects of interest.

The initial step in estimating the volume of data needed to achieve these goals is to define the data size for the two basic components of SDA: tracking and characterization. For tracking, the core information needed is the orbital definition encapsulated, for example, by a two line element set. This fundamentally describes an object with a unique identifier, as well as its position, velocity and direction. This information allows the prediction forward (or

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Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **SEP 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**

4. TITLE AND SUBTITLE **Space Domain Awareness**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Defense Advanced Research Projects Agency,675 North Randolph Street,Arlington,VA,22203-2114**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
In Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS), 11-14 Sep 2012, Maui, HI.

14. ABSTRACT
While Space Domain Awareness (SDA), including all of space surveillance and characterization of all space objects and environments, is critical for national and economic security, SDA capabilities cannot be developed independent of cost. This presentation will describe a new approach to SDA being developed by the Defense Advanced Projects Agency (DARPA) and other agencies. This approach endeavors to integrate the data from a wide range of current and future SDA capabilities for a fraction of the current costs by utilizing a new methodology for obtaining data. This approach will not just provide more SDA data for a reduced cost, but has the potential to also increase the amount of knowledge gained from the data.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

backward) in time, but the accuracy degrades as the amount of propagation time increases. Thus, the need to maintain a certain average level of accuracy in the tracking catalog will also influence the number and frequency of observations required. Characterization implies a much different level of knowledge. Object characterization implies some resolution of an object's features and/or behavior. Photometric signatures of brightness vs. phase angle and 2-D images of an object are two notable examples which can be used to form an estimate of the amount of information required to characterize a space object.

Another key parameter to be considered is the frequency of observation. This sampling rate varies depending on the characteristic timescale with an object changes, and the tracking accuracy desired. Thus, the rate can be quite different, in general, for passive and active objects. Passive objects change position and direction only under the influence of natural events and perturbations, such as atmospheric drag, and these factors typically change orbits over timescales of days to months. In contrast, active satellites can maneuver at virtually any time, and alter their orbital path on much shorter timescales of several hours.

These factors can be combined into a parametric sum which coarsely defines the total data needed to form a comprehensive awareness of the orbital population. Here, we will estimate the reduced data required. Implicit in this estimation is elimination of redundant, stale, and/or inaccurate observations, as well as extraction of the useful information from the raw data. The raw data volumes (CCD images, for example) will greatly exceed these estimates. Though a high fidelity model would require more terms, the equation given below includes the dominant terms which account for the vast majority of the data volume in the estimate:

$$\mathrm{B}_{tot} = \eta N_p \left(\frac{\beta_{mo}}{\tau_{mo\_p}} \right) + \eta N_a \left(\frac{\beta_{mo}}{\tau_{mo\_a}} \right) + \frac{\eta}{\gamma} N_a \left(\frac{\beta_{img}}{\tau_{img}} \right) \tag{1}$$

Where N_a , N_p are the number of active and passive objects; β_{mo} , β_{img} are the bytes/observation for metric observations and images; τ_{mo}, τ_{img} are the time between observations; η, and γ are scale factors that account for relative orbital accuracy goals for the various components of the total, as well as normalize the sum to account for inefficiencies such as false detections, uncorrelated targets, and verifications. Note that there is no component of the total for images of passive objects (debris), as it has been assumed there is no need for detailed inspection of these objects on a regular basis.

Next, it is useful to define the values of these parameters that approximate the current and future state of the space domain. The current catalog and network performance is to be compared to threshold and objective goals for Space Domain Awareness. The values are assumed are listed in table 1:

Table 1: Parameters used in estimating data needs for SDA

	Current	***Threshold***	***Objective***
β_{mo} , β_{img}	0.1, 10Kb	0.1, 10Kb	0.1, 10Kb
Number of Objects (N_a , N_p)	4K ,14K	5K,100K	8K, 150K
Update period (τ_{mo_p}, τ_{mo_a}, τ_{img})	3, 3, 300 days	3, 1, 45 day	3, 0.5, 30 days
η, γ	6,5	8, 5	12, 5
Size Object (near/deep)	10cm/30cm	> 3 cm/10cm	> 1 cm/5cm
Orbital Vector Accuracy	5km	500 m	100 m
GB/Year of relevant data	**~1.5**	**~12**	**~30**

The increasing values of the η parameter are due to the ever tighter goals for orbital vector accuracy. Their relative values are estimated via the simplifying assumption that the propagation error over time is proportional to the square of the update period divided by the square root of the number of observations used to create the track. The absolute value of η is calibrated based on DARPA estimates of the current data generation capacity of the SSN. The value of γ is estimated based on future surveillance need scenarios, but there is no large-scale, systematic effort to collect such data in place today, so the current value may be regarded as relatively uncertain.

This calculation indicates that the future need for SDA data will indeed be quite large, and an order of magnitude or greater than the data volumes being routinely captured and processed today.

3. DATA SOURCES

Any assessment of how to acquire this information must also consider the requirements and limitations of the physical hardware tasked with obtaining the measurements. Here it is useful to make a coarse separation between "near" and "deep" space. The convention will be used that near space corresponds to an orbital altitude of 2,000km or less, and deep space includes all objects with higher altitudes. For each of these regimes, different sensors are available, and different sensing requirements apply. For instance, in near space, radar is a very effective detection and tracking tool, capable of very high search rates and tracking objects <10cm in size. Optical systems detecting near space objects require very wide fields of view to conduct rapid surveys, because these objects transit the sky fairly rapidly. Additionally, traditional imaging is possible with reasonable size apertures, and very detailed images can be obtained with large telescopes such as the AEOS system. At higher altitudes, such as geosynchronous orbits, the situation is much different. Radars become limited in utility due to the beam size expansion and corresponding signal losses. Optical observations, however, become more effective at broad area detection and tracking, with the trade-off that larger apertures are also required to compensate for the reduced optical signal. Resolved images of objects at GEO altitudes are an extreme technical challenge, and thus characterization of deep space objects is accomplished through other means, such as photometric signatures (spectral and/or temporal).

Of all the remote sensing methodologies available, optical telescopes are one of the most ubiquitously available and low cost. Thus, this paper will examine optical systems as SSA data sources, but in practice, a number of other remote sensing systems and methods could be employed. Using the rough breakdown of data types and observation regimes just described as nominal divisions, one can determine coarse performance objectives for these different types of data. The performance objectives can then be translated into approximate hardware bounds in terms of aperture sizes and field-of-view.

Table 2: Aperture diameter and field-of-view bounds for optical observations of space objects of varying size and altitude

	Obj. size/resolution		**Aperture size**		**Ω(arcmin^2)**	
	Min (cm)	Max (m)	Min (cm)	Max (m)	Min	Max
Near metric observation	1	10	5	1	1E4	1E6
Near images	10	1	20	3	50	1000
Deep metric observation	5	10	25	10	1	1E4
Deep photometry	5	10	40	4	1000	3E4

Having partitioned the information desired into coarse hardware requirements, one can make comparisons to various systems currently in existence. Figure 1 shows the results of a limited survey of optical telescopes around the world. A sampling of major international installations, mid-sized astronomical assets, amateur observatories and commercial systems is shown, with the approximate bounds defined by in Table 2 overlaid. Clearly there is significant overlap between the data needs of SDA and the observing systems already operating.

Leveraging existing non-traditional data sources promises high value, since there would be little to no investment cost to procure land rights, build or independently maintain the facilities and hardware. Furthermore, this approach can increase the geographic coverage and availability of the network, reducing sensor bias. Of course, due to the disparate operators and hardware characteristics, and well as the often time-shared nature of these observatories, efficient utilization and data fusion is a non-trivial task that will require innovative solutions. If successfully implemented so that the information is coordinated and non-redundant, these data sources could greatly contribute to global space domain awareness.

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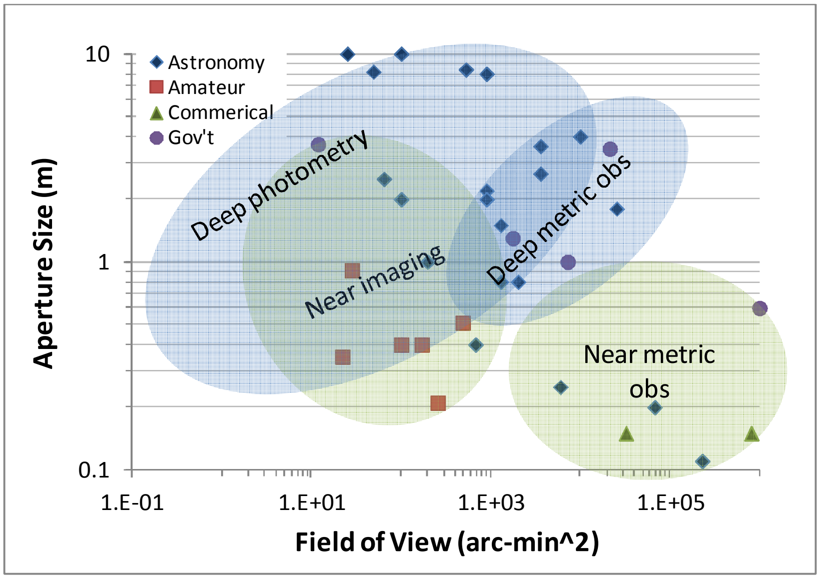

Figure 1: Aperture size and Field-of-view for various optical observatories worldwide

4. CONCLUSION

As the space domain grows ever more accessible and the resident space object population increases, the amount of data required to maintain adequate domain awareness and ensure safe operations will greatly increase. This data can be provided by a number of different means, and a substantial base of observatory assets exist with capabilities well-matched to the projected need. Additionally, modern cameras and computer controlled mounts enable even backyard astronomers to acquire data of potential utility and meaningfully participate. The flexibility, responsiveness, and efficiency of the Space Surveillance Network might be significantly enhanced if these data sources can be harnessed in a coordinated, systematic way. DARPA has been investigating methods that support this kind of dynamic and distributed architecture within the current SSN architecture, and will continue to investigate opportunities to utilize non-traditional data sources of value to the space surveillance community.

5. REFERENCES

1 "ESA Space Debris: history and background", http://www.esa.int/esaMI/Space_Debris/index.html

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